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KELLY AIR FORCE BASE MAINTENANCE HANGAR: CONSTRUCTION FEATURES

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and C. W. Edwards

CONSTRUCTION DIVISION

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FOREWORD

In the past decade, remarkable progress has been made in the construction of large span, single story structures. The engineer of today, equipped with the facility of modern techniques is faced with a variety of important and decisive factors in the selection of method of design, construction and the application of structural material. To evaluate a building project, one must have intimate knowledge of the natures of the problems involved and the scope of the work within the established limitations of the functional requirements. It is intended, in this three-paper symposium, to bring out the interesting features and kindred interrelationships in planning, design and construction of the large span, single story hangar structure with all the supporting utilities.

The three papers comprising the symposium on the "Kelly Air Force Base Maintenance Hangar" are sub-titled "Planning" by Louis A. Nees, A.M. ASCE, Proceedings Paper 852; "Engineering Design Features" by N. H. Aslanian, A.M. ASCE, Proceedings Paper 853; and "Construction Features" by W. H. Fasshauer, A.M. ASCE, and C. W. Edwards, Proceedings Paper 854.

The first paper of the group describes the basic studies of the Air Force operational and functional requirements. The major feature of interest is in its provision to enable maintenance on a simultaneous "production line" and "stall" basis for all types of aircraft, including the largest bombers (B-36, B-52, and B-47) in operation today. The planning established a facility consisting of a hangar 2,000 ft. long, 300 ft. wide area flanked by a shop structure 250 ft. wide, plus a maintenance type apron of 300,000 square yards. As a result, aircraft can be handled on a production line basis and "staged" in or out of the line depending on the scope of work involved while at the same time the facility supports "stall" type overhauls on the apron.

The second paper of the group covers mostly design, fabrication and method of erection of the principal hangar structure, and also general features of interest, including foundations, apron slabs and all the supporting facilities.

The last paper of the symposium discusses in detail all the construction activities and the execution of the project up to completion. This maintenance hangar facility totalling a record-breaking hangar and shop roof area of 23.4 acres and measuring slightly less than a mile in perimeter will be completely ready for occupancy by mid-February 1956, and will be the world's largest and most modern hangar structure.

The first two papers of the Symposium on "Planning" and "Engineering Design Features", by Messrs. L. A. Nees and N.H. Aslanian, respectively, have been programmed to be presented at the American Society of Civil Engineers' meeting in Dallas, Texas, in February 1956.

Reprints from this publication may be made on condition that the full title of paper, name of author, page reference (or paper number), and date of publication by the Society are given.

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KELLY AIR FORCE BASE MAINTENANCE HANGAR CONSTRUCTION FEATURES

W. H. Fasshauer,¹ A.M. ASCE and C. W. Edwards²

SYNOPSIS

The procedures used in constructing and erecting a new large-span aircraft hangar and its integrated facilities are described in this paper. General features of interest, including site preparation, caisson foundations, apron slab construction, erection of structural steel and all the supporting utilities are discussed. It is assumed that the reader is acquainted with the planning and engineering design features of this project, as presented in the first two papers of this symposium by Messrs. L. A. Nees³ and N. H. Aslanian,⁴ respectively.

INTRODUCTION

A huge single-story building, now under construction for the United States Air Force at Kelly Air Force Base, San Antonio, Texas, will be considered the world's largest and most modern maintenance hangar when completed by the end of this year, 1955.

The enormity of the project can be best described by a simple reference to the areas covered by the principal structures and supporting facilities. Hangar area - 300 ft. x 2000 ft.; Shop area - 250 ft. x 1650 ft.; Second Floor Office area over the Shops - 250 ft. x 250 ft.; Boiler House area - 55 ft. x 83 ft.; Pump House area - 46 ft. x 46 ft.; New Apron area - 300,000 sq. yds.; Total Building area under one roof - over 1,000,000 sq. ft., or 23 acres; Perimeter of the hangar and shop - nearly one (1) mile (Fig. 16).

Extreme care was exercised in organizing and directing the methods of erection and construction of the many complicated facilities that went into this project. For example, the Air Materiel Command, U. S. Air Force, awarded the contract for Field Engineering Services to the designers of the project, the Kuljian Corporation, in order to maintain close control and coordination of all operations during the entire construction program.

Bid Estimates and Contract Award

Of the 13 contractors bidding for construction of this huge Air Base facility, four bidders came within 2% range of the low bid, while the highest bidder was in excess by only 15%. An interesting variation in the bidding became apparent when a breakdown of bid estimates from these four bidders

1. Manager of Engineering, The Kuljian Corporation, Philadelphia, Penna.
2. Chief Resident Engineer, The Kuljian Corporation, Philadelphia, Penna.
3. Chief, Engineering Branch, Installations Div., Hq. AMC, Wright-Patterson Air Force Base, Ohio.
4. Designing Engineer, The Kuljian Corporation, Philadelphia, Penna.

BIDDER NO.	1	2	3	4
SITE PREP., CAISSONS & BORINGS	\$ 475,200.40	\$ 566,037.30	\$ 512,560.67	\$ 497,794.03
HANGAR	5,493,886.54	5,625,604.00	6,018,804.78	6,033,273.59
SHOPS	3,518,818.00	3,113,000.00	3,324,441.00	3,067,165.00
BOILER	352,313.00	310,000.00	343,851.00	346,693.00
SPRINKLER WATER SUPPLY	268,397.00	300,000.00	271,600.00	272,390.00
APRON	1,885,674.56	2,117,313.86	1,777,838.13	1,912,231.38
EXTERIOR SANITARY SEWERS	25,096.94	30,772.00	22,861.44	19,276.05
EXTERIOR STORM DRAINS	388,182.40	480,422.80	368,320.77	521,569.87
WATER DISTRIBUTION	76,795.70	79,220.00	79,849.24	90,084.09
EXTERIOR GAS DISTRIBUTION	13,223.70	12,101.25	10,652.10	14,322.99
EXT. PRIMARY ELEC. SERVICE	189,407.00	200,000.00	189,000.00	148,200.00
TOTAL	\$ 12,686,995.24	\$ 12,894,471.21	\$ 12,920,079.13	\$ 12,923,000.00
ALTERNATES				
USE PROTECTED METAL SIDING	+ 69,000.00	+ 50,000.00	+ 120,000.00	+ 19,000.00
USE WELDED STUD FASTENERS	- 2,950.50	NO CHANGE	- 2,950.00	- 850.00
USE FIBERBOARD ROOF INSUL.	NO CHANGE	NO CHANGE	NO CHANGE	+ 3,000.00
USE REINF. CONC. WATER PIPE	- 5,000.00	- 10,000.00	+ 7,500.00	NO BID
DELETE DELUGE SPRINKLERS	- 445,572.00	- 550,000.00	- 500,000.00	- 555,000.00
BEGIN	10 DAYS	10 DAYS	30 DAYS	10 DAYS
COMPLETE	800 DAYS	700 DAYS	900 DAYS	700 DAYS

BIDDER NO. 1, FARNSWORTH & CHAMBERS CO., INC.
HOUSTON, TEXAS

+ DENOTES INCREASE
- DENOTES DECREASE

ESTIMATES SUBMITTED BY THE
FIRST 4 CONTRACTORS

TABLE - 1

ITEM	\$ TOTAL CONTRACT PRICE	ITEM	\$ TOTAL CONTRACT PRICE	ITEM	\$ TOTAL CONTRACT PRICE
<u>SITE PREPARATION</u>	<u>9.749</u>	11. ABOVE GROUND GAS	.006	36. STRUCT. STEEL BOILER HOUSE	.329
1. REMOVAL OF EXIST. PAVEMENTS	.260	12. ABOVE GROUND ELECT. SERVICE	5.004	37. STEEL ROOF DECKING	.088
2. EXCAVATING & GRADING	.430	13. SPRINKLER SERVICE	3.869	38. SIDING	.040
3. BORING FOR CAISSONS	.010	14. HEATING SYSTEM	1.994	39. PLUMBING	1.714
4. PLACING CAISSONS	2.697	15. COMPRESSED AIR SYSTEM	.315	40. BOILERS	1.874
5. EXTERIOR SANITARY SEWERS	.195	16. EXTERIOR SIDING	1.833	41. ELECTRIC WORK	.189
6. EXTERIOR STORM DRAINS	2.970	17. STEEL ROOF DECKING	2.392	42. 550,000 GALLON TANK	.529
7. WATER DISTRIBUTION	.602	18. INSULATION & ROOFING	3.790	43. PUMP HOUSE	.106
8. SPRINKLER SUPPLY MAINS	.988	19. PAINTING	1.017	44. SIX FIRE PUMPS	.374
9. EXT. PRIMARY ELECT. SERVICE	1.493	20. WALL INSULATION	1.833	45. PRESSURE PUMP	.008
10. EXT. GAS & TEST SERVICE	.104	21. MASONRY	2.265	46. ELEC. WORK FOR PUMP HOUSE	.481
<u>HANJAR AND SHOPS</u>	<u>74.925</u>	22. PLUMBING FIXTURES	.026	47. SPRINKLER MAIN	.615
1. GRADE BEAM & FOUNDATIONS	.200	23. ELECTRICAL FIXTURES	.770	<u>APRON</u>	<u>15.326</u>
2. SLAB	1.543	24. OVERHEAD CRANES	.210	1. EXCAVATION & COMPACTION	.345
3. REINF. STEEL DELIVERED	.801	25. DRAFT CURTAINS	.452	2. ELECTRICAL WORK	1,929
4. ANCHOR BOLTS	.200	26. SLIDING DOORS	2.357	3. UTILITIES UNDER SLAB	.190
5. STRUCT. STEEL DELIVERED	20.665	27. DOORS - OTHER THAN SLIDING	.341	4. TIE DOWNS	.084
6. STRUCT. STEEL ERRECTED	10.332	28. AIRPLANE SCALE	.084	5. SLAB CONCRETE	11.893
7. UNDERGROUND WATER	.602	29. MOVABLE METAL OFFICE PART.	.130	6. PAVING BITUMINOUS	.778
8. UNDERGROUND GAS	.104	30. ACOUSTICAL CEILING	.078	7. CONNECT. TO PUMP STA. NO. 314	.001
9. UNDERGROUND ELECT. SERVICE	4.005	31. RECORD VAULT	.006	8. CONNECT. TO BLDG. NO. 307	.001
10. ABOVE GROUND WATER	.057	32. ELEVATOR	.110	9. LACKLAND RD. CONNECT. TO MAIN	.001
		33. HARDWARE	.910	10. FINAL CLEANUP	.104
		34. VENTILATION SYSTEM	.228		
		35. BOILER HOUSE			

SEPARATE ITEMS IN PERCENT OF TOTAL CONTRACT COST

TABLE - 2

(Table 1) revealed wide differences in separate items, but little difference in the overall estimates.

The contract for construction work was awarded to low bidder, Farnsworth and Chambers Company, Inc., Houston, Texas, at a cost of \$12,687,000. The time necessary to complete the entire project was estimated to range within a period of 800 calendar days. At the initial stages of construction, a progress chart was prepared for all principal construction operations and their supporting utilities. The cost for each individual item was determined in terms of percentage of total contract costs and is presented for evaluation purposes (Table 2).

On November 17, 1953, the Government gave notice to proceed, and one week later, the contractor's organization and equipment arrived at the job site ready to start with survey, grading and drainage lines.

Engineer - Inspector Organization

The size of this project and the great volume of work to be inspected, required a well organized and efficient staff of resident engineers with adequate experience in various phases of construction work. A brief description of the organization and inter-departmental liaison procedures will give a better understanding of the methods employed to safeguard the construction activities.

As direct representative of The Kuljian Corporation, the Chief Resident Engineer was charged with full responsibility for the supervision of all resident engineers, inspectors, survey parties, and office force; for the administration of all record data, progress reports, payment estimates, correspondence to all Government Agencies involved, testing laboratory contract and services, coordination of various Government Using Agencies and liaison between Military and Civilian government personnel.

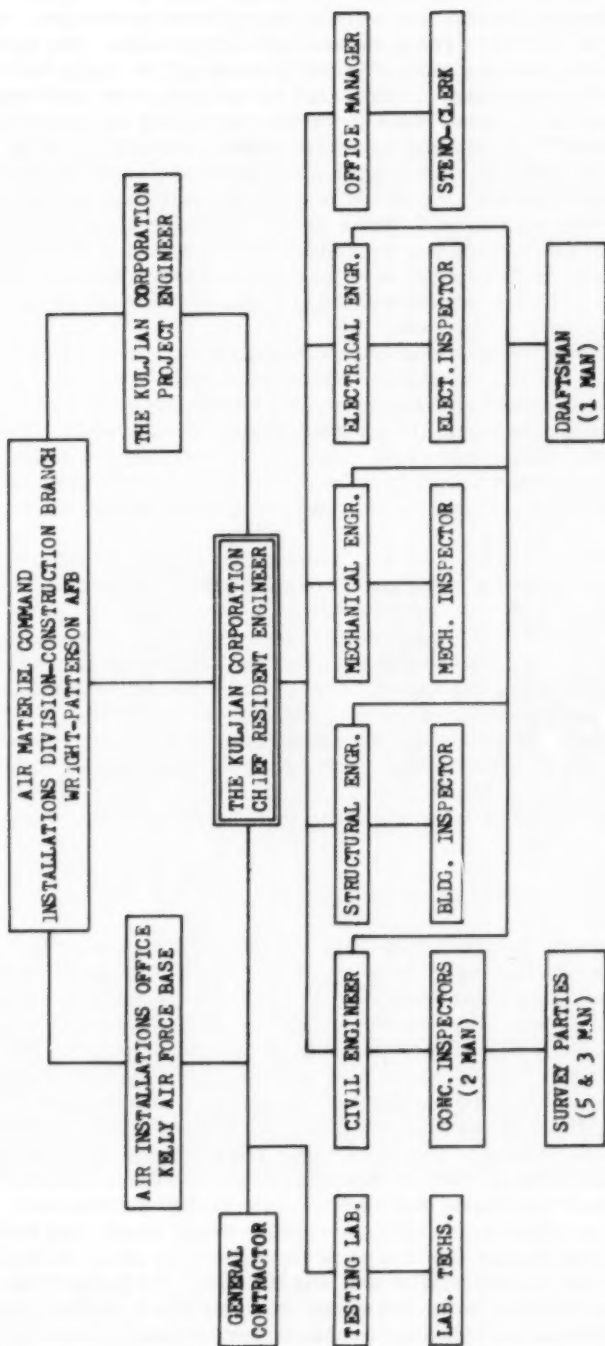
In general paper work flowed from the contractor to the Chief Resident Engineer who, after furnishing additional data, justification and comment, forwarded the file to the Air Materiel Command, Wright-Patterson AFB, Dayton, Ohio, through the Air Installations Office, Kelly Field, with copies to the general contractor, the contracting officer, the Kuljian Home Office and other agencies, if particularly involved. Instructions and decisions from Air Materiel Command were passed down through the same channels in reverse order (Chart 1).

The Chief Resident Engineer's staff was augmented or decreased as exigencies of construction required, thus maintaining complete field engineering and inspection at a low cost to the Government.

Site Preparation

Grading of the site area involved the removal of 90,000 square yards of existing concrete pavement and taxiways, and removal of all soft or unusable soil encountered at the hangar and shop areas. The concrete debris was classified and most of it used to create embankments along the Westover Road within the Base. All usable soil, as approved by the Chief Resident Engineer, was mixed, harrowed, disked, etc., to meet required compaction qualities, and distributed where needed.

The rough grading of the apron area having been completed, finish grade stakes were set at 25 ft. intervals in both directions and the surface scarified and bladed with a maintainer. For the compaction of clay fills, individual



ORGANIZATION CHART

CHART - 1

drums of sheep's-foot rollers, filled with water and weighing about 5 tons, were attached in tandem fashion, and together were drawn by tractors. At one time, about 6 or 7 of these group rollers were in operation. The specified 600 psi footprint pressure was sufficient to crush all the lumps and bulk until it was properly compacted. Compressed air tampers were used where power rollers could not be used. Each layer was separately compacted between 95%-100% density at optimum moisture content as specified in the modified A.A.S.H.O. methods. When necessary, water was sprinkled in increments not exceeding 2% by dry weight of the 6 in. compacted layers. The black clay was a somewhat difficult material to bring to the optimum moisture content because of its high plastic characteristics and slow moisture absorption qualities. Each application of increment of water was allowed to remain some length of time without working in order to allow for absorption of water and to reduce the stickiness.

Immediately after grading operation and rolling by the sheep's-foot rollers, the surfaces of both fill and cut of each section were rolled by 3 passes of a 10-ton 3-wheel power roller in order to provide smooth and hard surfaces which would minimize the evaporation and infiltration of rain water. This treatment was also meant to reduce the tendency for swelling and softening of the surface of compacted subgrade soils. Field control tests were performed before and after each rolling operation in order to assure the required degree of compaction.

The surface of the subgrade soil was tested with a 10-foot straight edge applied both parallel to and at right angles to the center line of the area. Any deviation in excess of 1/4" was not permitted. In areas where a change in the type of soil occurred at the surface of the subgrade, the soil was blended and intermixed to eliminate sharp demarcations, and to provide uniform soil conditions of equal soil bearing values. This blending was done to a depth of from 12" to 18", and to a width of from twenty (20) to twenty-five (25) ft. at each side of the line of demarcation. Immediately prior to placing concrete slabs, the subgrade was rolled with a 10-ton, 3-wheel power roller with not less than 6 passes. When the subgrade was forced below its proper level, additional fill was deposited in the low areas to bring the subgrade to the proper level.

Underground Service

To accommodate the facility a new sixty-six (66) in. diameter, T & G concrete storm water drainage line was installed, running a distance of nearly one mile from the hangar site to Leon Creek. It was deemed advisable to have this drainage system in operation promptly so as to keep the site as dry as possible. The contractor started this main drainage line at Leon Creek terminus, with direction of placement toward the hangar. Depth of excavation ran from twenty (20) ft. below grade at the hangar to nearly thirty (30) ft. below grade going under the military highway. Rigid field inspection was necessary to maintain the specified slopes, backfill and the precise joining of the sections of this sixty-six (66) in. line (Fig. 1).

At the same time installation of a 13.8 KV underground transite duct system, encased in concrete, for primary electric power supply was underway running from the hangar site to a point about one mile away, at the east side of the base, where a sub-station unit was to be built for power feed. All other underground utilities, water lines, gas lines, air lines, sanitary sewers, electric duct, telephone and fire alarm conduits were properly installed and backfilled, and were kept in readiness for the concrete slab to follow.



854-7

Caisson Foundations

Upon completion of the subgrade preparation, caisson work was initiated from the Northeast corner of the shop proper, and was carried toward the South and West. The number of caissons for all buildings, including the Boiler and Pump Houses, amounted to a total of 746, with the diameter ranging from 18 in. to 60 in., and with an average caisson depth of 60 ft. In some instances the caissons went down to 68 ft. below grade to insure the required bearing value. Breakdown of the lengths and diameters of all caissons used is as follows: 18-in. diameter - 38,000 ft.; 24-in. diameter - 5,300 ft.; 30-in. diameter - 2,250 ft.; 36-in. diameter - 400 ft.; 42-in. diameter - 550 ft.; and 60-in. diameter - 1,150 ft. The unit cost of the caissons varied from \$5.50 to \$47.50 per linear foot. In addition, 24 test borings were made with a total footage of 236 ft. to reveal the nature and thickness of the soil strata surrounding and underlying the caisson foundations.

Practically all test borings were drilled in Nevera clay, which, being exceedingly firm in substance, permitted clear and sharp cuts without trace of hole pockets. When exposed to atmosphere, this clay became very hard and neared the density of trap-rock. However, in its natural state, sheer cut with an auger was smoothly performed.

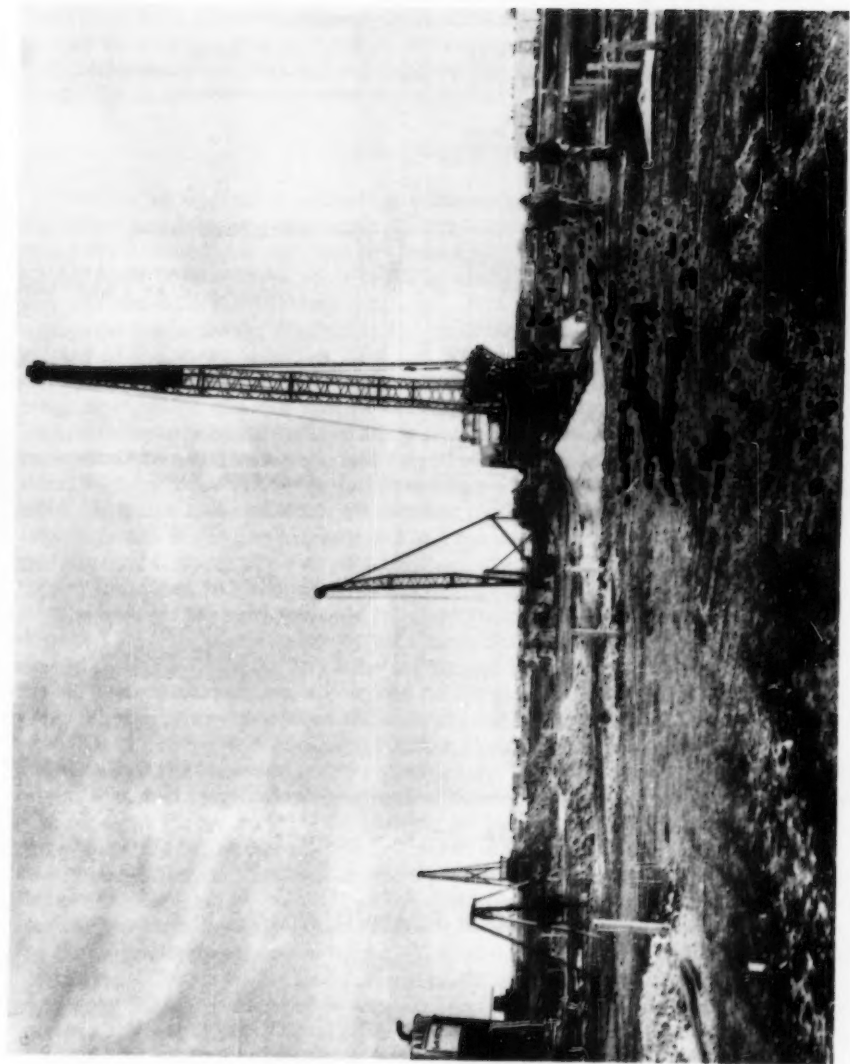
Sides and bottoms of all caisson openings were inspected prior to the setting of reinforcing steel cages. Inspection was made by either structural engineer or inspector assigned to this work. Flashlight photos were taken to study the actual conditions within the caissons. In some instances the structural engineer entered the 60-in. diameter caisson openings to inspect the conditions of the belled bottoms.

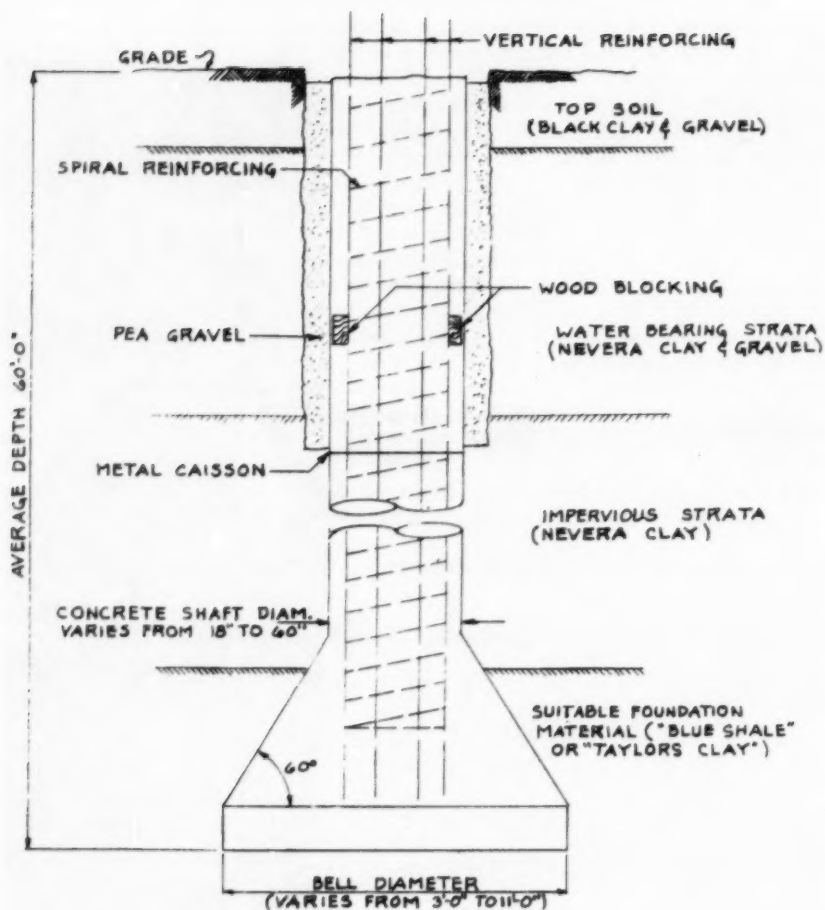
Construction of the so-called under-reamed piling or caisson foundation was as follows:

1. Oversized shaft was drilled in the ground after the completion of surface compaction (Fig. 2).
2. A one-piece metal caisson tube was set plumb, and driven into the impervious material (Fig. 3).
3. Pea gravel was placed around the side of the caisson tube.
4. Excavation was continued below the caisson tube to a suitable foundation.
5. An under-cutting bit or reamer was then used to undercut the bell bottom to required dimensions.
6. After inspection of the foundation material and cleaning out of the loose dirt, reinforcing steel cage was lowered into the shaft.
7. Concrete was then poured into the shaft in one continuous pour, from the bottom of the piling to the top of the caissons.
8. The caisson metal tube was immediately withdrawn after the concrete operation was completed.
9. The top of the caisson pilings was brought to a proper grade thus completing the caisson operation.

The caisson caps were then installed. With the aid of the survey crew, a thorough check was made of elevation and location of anchor bolts and bed plates.

With reference to the Architect-Engineer's plans and specifications, 30-in. diameter battered caisson supports were indicated for support of the 550,000 gallon water tank to be used with the deluge sprinkler system. Field conditions, however, did not favor recommendation for battered caissons, and





TYPICAL UNDER-REAMED PILING

FIG. 3

upon the Contractor's request, the caissons were redesigned to be plumb and 42-in. in diameter with added reinforcing steel to take care of the induced forces.

From the time of construction of the caisson foundations, provision was made by establishing thirty (30) bench marks to observe possible settlement or heaving of the caissons by recording periodical readings. These readings were made to a 1/1000 foot accuracy. The recorded vertical movements have been very small in magnitude, and only an average settlement of 0.008 ft. and an average rise of 0.006 ft. have been observed up to this date. These periodical readings will be continued during and after construction to safeguard the proper functioning of the structure and form a permanent record.

Large-Scale Paving

The paving operation followed a conventional pattern and was similar to highway work in many respects. The concrete aggregate sand and cement were dry batched, two batches to a truck, at a plant located on a railroad siding about a mile from the site. The concrete was mixed in twin drum, one and one-half yard pavers.

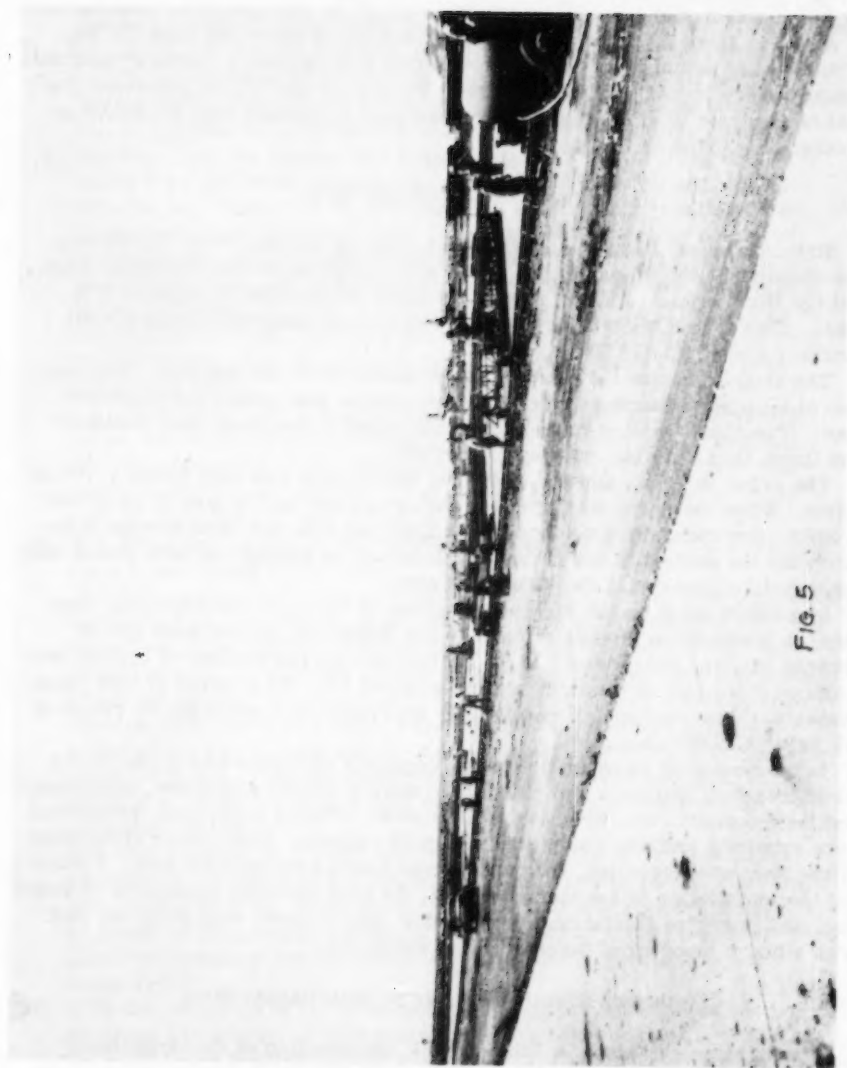
Large-scale paving started in the morning at 8:00 a.m. on the Northeast corner of the apron, running East and West along the North edge. The placing operation of concrete got underway by first pouring a 25-ft. strip, then missing three strips and pouring another, once again missing three and pouring another, then backtracking and pouring in-between. These 16-in. thick pavement strips, running the full length of the apron, were poured in two lifts, a 12-in. base and 4-in. top of the same material, monolithic with the base. It was a little difficult to keep the slab contours lined up and keyed together with shear keys, but it worked out satisfactorily. By 2:30 p.m. in the afternoon, about 500 cu. yds. had been poured. However, pouring continued and about 1000 cu. yds. were poured for the first day's run.

The overall paving operation followed in this pattern: Construction joint dowels 1-1/2 in. in diameter by 3 ft. long, spaced 18 in. on center were placed in holes in the sides of the forms and secured. Two, and sometimes three, pavers were used, one or two on the base and one following up with 4-in. topping after #6 welded wire mesh, spaced at 6 x 6 in., was placed (Fig. 4). A paving and trailing gang vibrators on two-foot centers, leveled and vibrated the base for mesh reinforcing. The top was brought to grade by transverse and longitudinal mechanical floats followed by hand floats and ten-foot straight edges, and finally finished by belting (Fig. 5). Apron outlets were installed in the apron directly ahead of the slab. Conduit was run directly under the slab and boxes were properly set and anchored. Tie downs were also installed in the slab as the slab progressed. Further hand finishing was required around grade beams, electrical and air outlets and along the dummy and construction joints. Liquid compound was sprayed on the slab for curing. Construction and dummy joints at 25-ft. spacings controlled cracking. Three-quarter inch asphalt impregnated expansion joint material was installed at approximately 500 ft. intervals.

Concrete control consisted of selecting one of several trial batches for proportioning the mix, and making test beams for every 250 cu. yds. Two concrete inspectors were employed, one on placing and one on finishing. The inspector on placing concrete made spot checks on the batching plant and kept a record of cement cars received. The actual concrete testing services were accomplished by a testing laboratory under a separate contract, and



Fig. 4



the technique of sampling and testing for three point break, etc., was the responsibility of the testing agency. Reports of these test findings, however, were then submitted to the Chief Resident Engineer for his review and approval. Approximately 300,000 square yards of concrete, or about 60 acres, were placed in 140 working days. Average pour was about 2,000 square yards per day.

To insure the necessary strength in concrete, forms for all self-supporting beams and slabs were not stripped prior to the time specified, which was seven (7) days for slabs, beam sides and beam shores, and fourteen (14) days for beam soffits and supports at the third points of the span after concreting.

A curing shed, 10' wide and 60' long was built to store and cure the 28, 60 and 90 day samples. At one period during this operation, several hundred samples were in this shed being cured. Purely for statistical purposes, the cost of concrete used for testing purposes only ran better than \$5,000.00 at contractor's price on the job.

Erection of Structural Steel

Structural steel for the entire project, totaling slightly over 11,800 tons was detailed at the Roanoke, Va., plant and fabricated at the Memphis, Tenn., and the Birmingham, Ala., plants of the American Bridge Division of U.S. Steel. This island of structural steel is now completely erected at a total contract cost of \$3,676,600.

The shop steel was the first shipment delivered to the job site. The erection of shop steel started in the northeast corner and proceeded south and west. The steel framing was erected and bolted in sections; then plumbed and lined, thus allowing riveting to proceed.

The error in grade allowed in setting base plates was kept below 1/100 of a foot. When the error was greater, the contractor had to take it up and do it over. American Bridge forces were supplied with new instruments to accomplish the desirable and necessary accuracy in setting the base plates and the overall alignment of the structural steel.

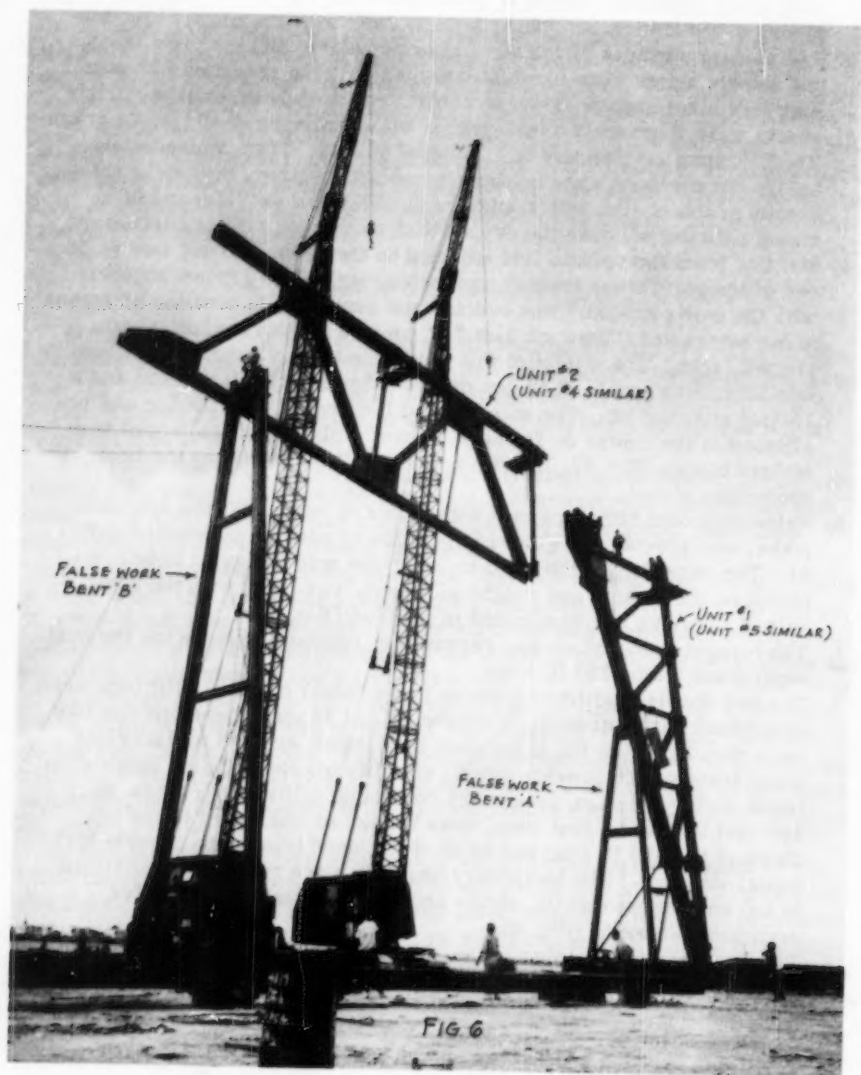
In a check made on the riveting progress in the first section of the shop steel, a tremendous amount of rejects was revealed. These were cut off, cleaned out, and re-riveted. In the second section the number of rejects was reduced from 14% of the first section to about 5%. As a result of this rigid inspection, this percentage was further decreased to a satisfactory result of 1% rejects in the shop area.

In the course of erection progress, complete coverage was made by the Chief Resident Engineer and his staff to assure proper alignment, plumbness, and field connections. Erection of shop steel, totaling 2,895 tons, proceeded very smoothly and was completed within 36 calendar days. After completion of the shop steel erection, the decking was started on the shop roof. Following the installation of the metal decking, the roof material consisting of vapor seal and fiberglass insulation was installed, and followed with 4-ply tar felt with a heavy mopping of tar and gravel surfacing.

Method of Erection for Large-Span Hangar Steel

About the second week in June of 1954, the erection of the large-span hangar steel got underway. The sequence of erection of any one of the principal hangar bay structures (300' x 400') were as follows:

1. The steel masonry plates were anchored in their indicated positions for the first unit bay.
2. The horizontal tie beams were assembled in their entirety directly over the trench, and it was wrapped with protective coating something similar to that used on high pressure gas lines, etc. It was coated again with heavy asphaltic coating to protect it from the elements and was placed in the trench.
3. The contact surfaces of the steel masonry plates and the rigid truss frame sole plates were furnished applied with the specified #22 gage stainless steel sheets. The two contact surfaces between these bright sheets were thoroughly brush-coated with a mixture of 40% flake graphite, 20% spar varnish and 40% mineral spirits. Then, immediately before the surfaces were brought in contact together, they were uniformly brush-coated with a mixture of 40% flake graphite and 60% steam cylinder oil over the dry varnish to provide sliding surface.
4. Starting from the column line adjacent to the shop, stiff leg unit #1 of one of the rigid truss frames was assembled on the ground, together with the sole plate, and was erected and supported in position by means of guy wires and falsework bent "A" equipped with a pair of 50-ton journal jacks. The weight of this assembled unit #1 was 43 tons, and it was lifted with a pair of 40-ton derricks having a 90-foot boom and a 15-foot attached jib. The sole plate at the heel of the stiff leg was positioned in the center on the steel masonry plate and was locked with wedged blocks (Fig. 6). The tie beam was then riveted to the heel connection plates.
5. Falsework bent "B", equipped with a pair of heavy 300-ton hydraulic jacks, was erected and guided in position to receive assembled unit #2. The assembly of the rigid truss frame unit #2 having been completed on the ground and weighing 56 tons, was lifted with the same pair of derricks and was bolted in position (Fig. 7).
6. The foregoing operation was repeated in similar sequence for the next rigid truss frame 250 ft. away.
7. The two double cantilever trusses immediately over the stiff legs were assembled on the ground. Weighing 23 and 32 tons, respectively, they were then raised to fill in between the already erected partial rigid truss frames. To provide lateral stability for the 250-foot longitudinal truss during erection, temporary horizontal stiffening trusses, each 130-feet long and 4 feet deep, were employed and bolted to the top chord of the 250 ft. long and 24-ft.-9-in. deep trusses to provide horizontal stiffness. The temporary bracings were removed after filling in top and bottom chords, struts and sway bracings required for permanent stability (Fig. 8).
8. The wall framing of column line "M" was erected to provide lateral stability in the longitudinal direction for the erected part of the hangar.
9. The cantilever ends of the double cantilever trusses were then assembled on the ground. Weighing approximately 7 tons, they were then lifted into position and the necessary bracings were filled in and connected.
10. With the exception of the erection of the longitudinal trusses and positioning and locking of sole plates, the procedure for the erection of the rigid truss frames for the remaining part of the first unit was repeated in a similar sequence (Fig. 8). The sole plate of unit #5 was left unlocked to adjust itself for temperature variations. In accordance to the design requirements the sole plate was placed in a calculated



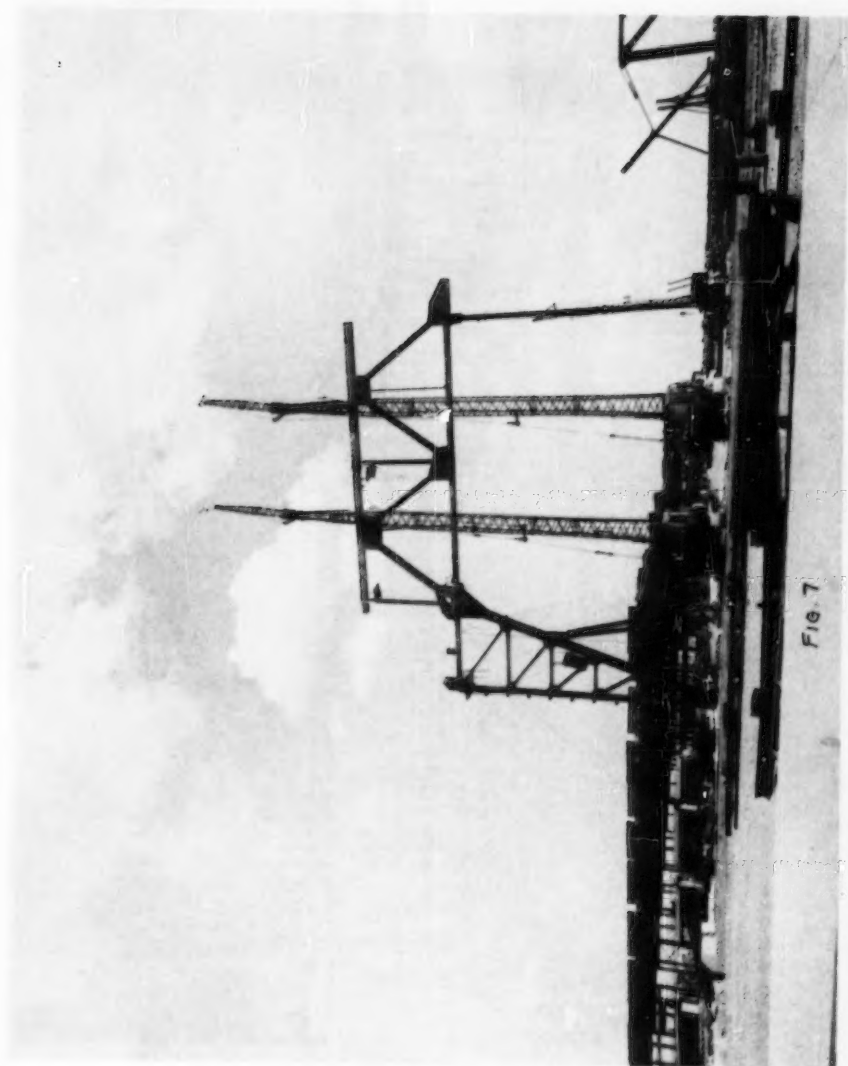
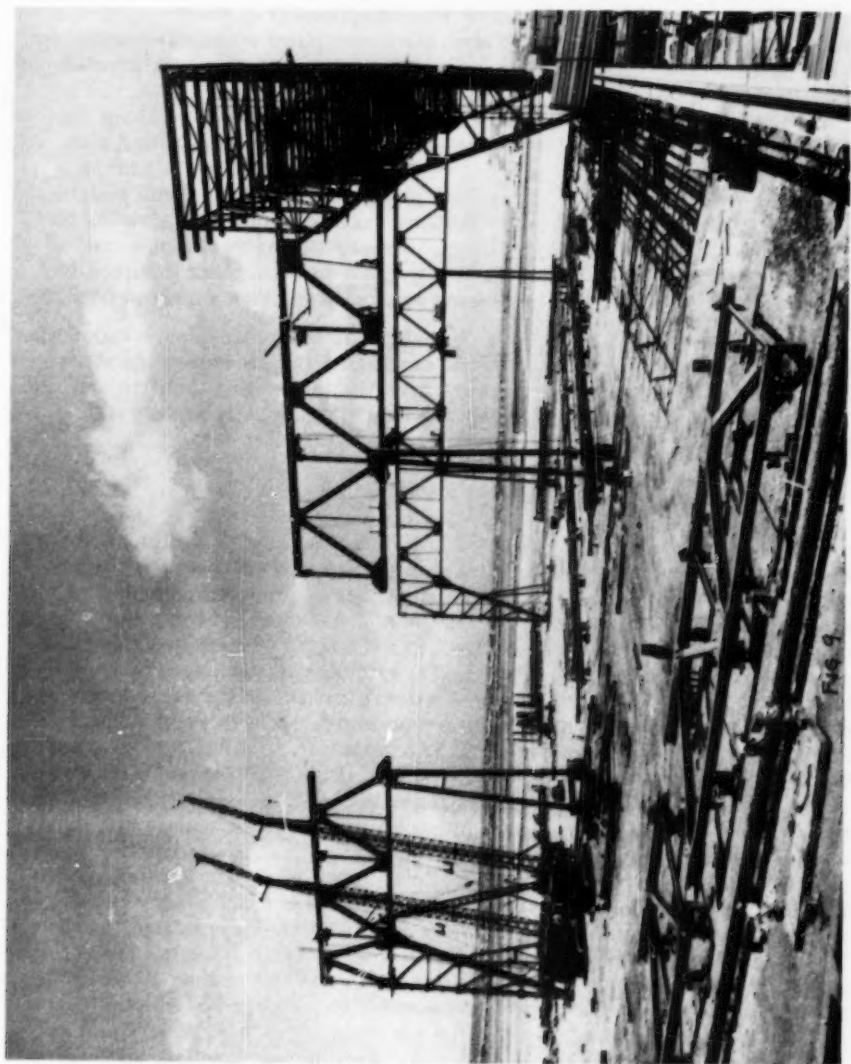


FIG. 7





"geometric" distance of approximately 1-3/8 in. toward center of hangar to provide connection of unrestrained tie member. This dimension is based on normal fabrication shop temperature of 68° F.

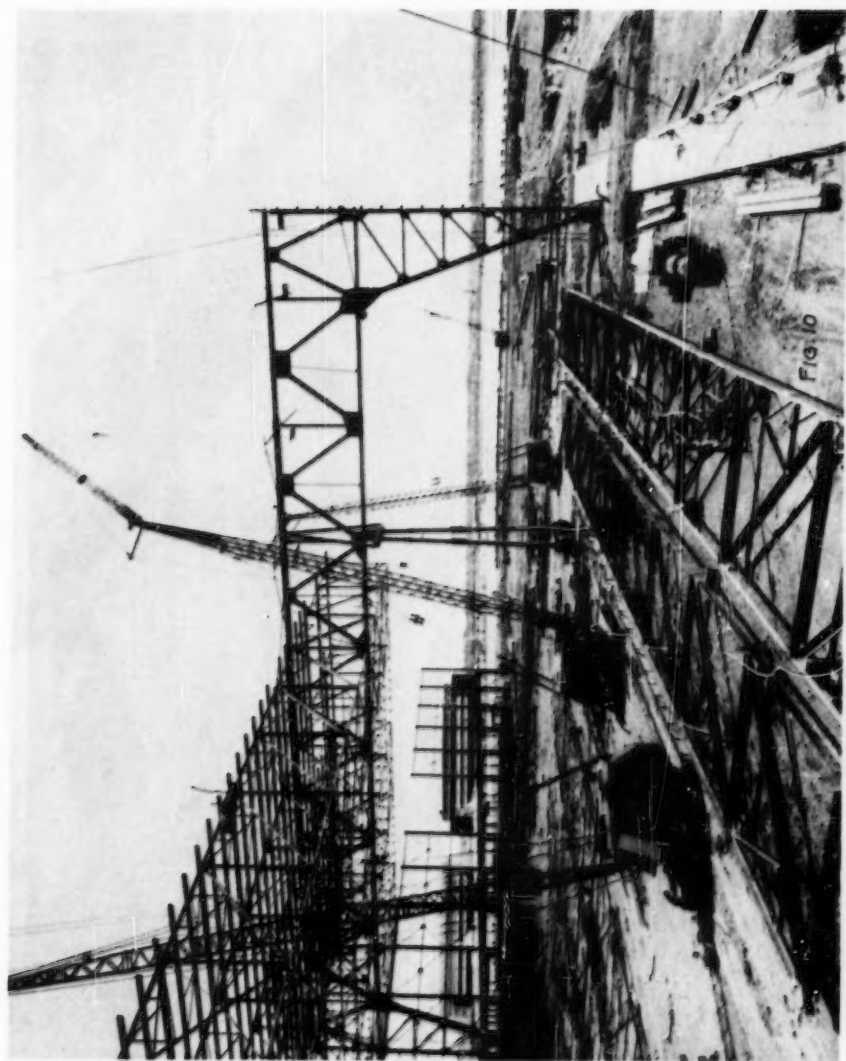
11. The center portion of the two rigid truss frames (unit #3), assembled on the ground, was then raised into position, and with the necessary fill-ins, was firmly connected. False-work bents were jacked up to the amount necessary to make the connections (Fig. 9).
12. The erection of double cantilevers was continued in the same sequence, building away from the shop proper until the entire bay was erected and filled in with bracings (Fig. 10).
13. The intermediate wall columns and bracings were erected along the spandrel trusses on the outside face. Falsework was removed after erection of all structural steel material and carried to the next bay.
14. The west legs of the rigid truss frames were not locked with wedges during construction in order to permit observation and determine the influence of temperature changes. Eventually the west legs were wedged in a final position when the entire dead load was in effect, and the slotted holes were leaded and concreted in place with lean concrete.

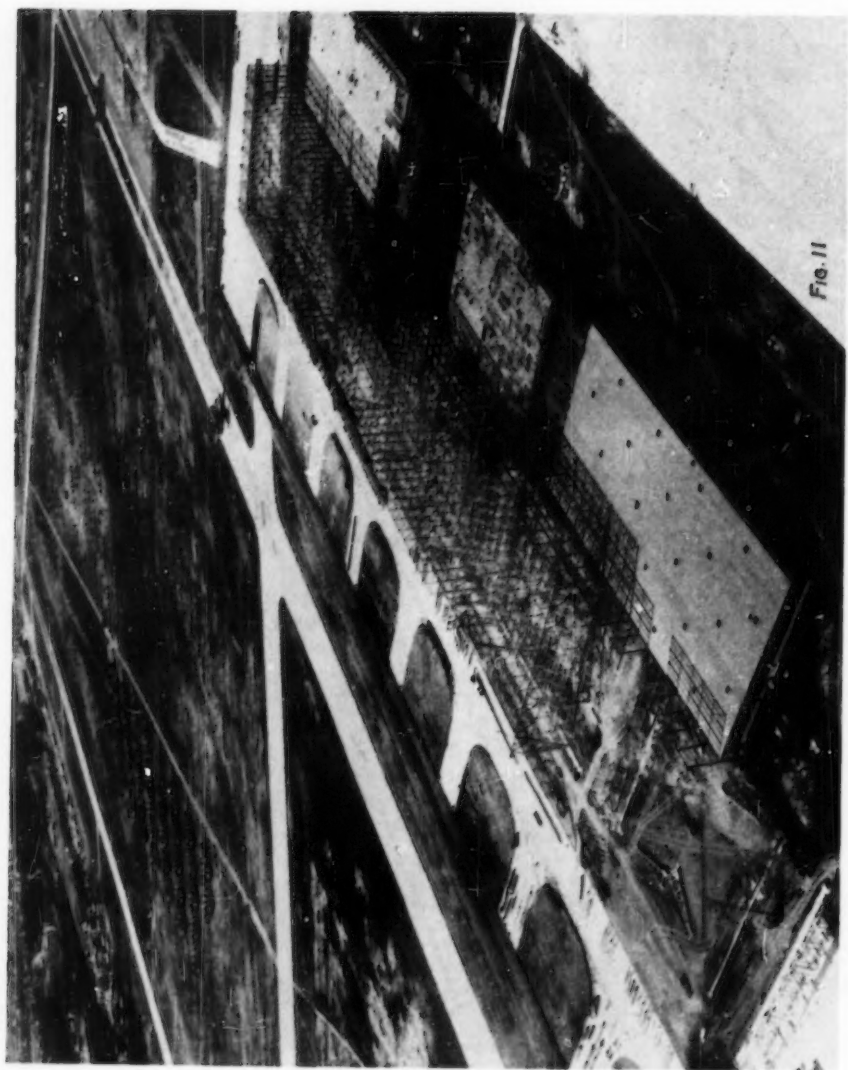
The erection of the first unit of the hangar structure progressed somewhat slowly owing to the many unusual field conditions and precautionary steps. As a result of the skill and experience acquired in erecting the first unit, the time schedule for completion of the other units was greatly accelerated (Fig. 11).

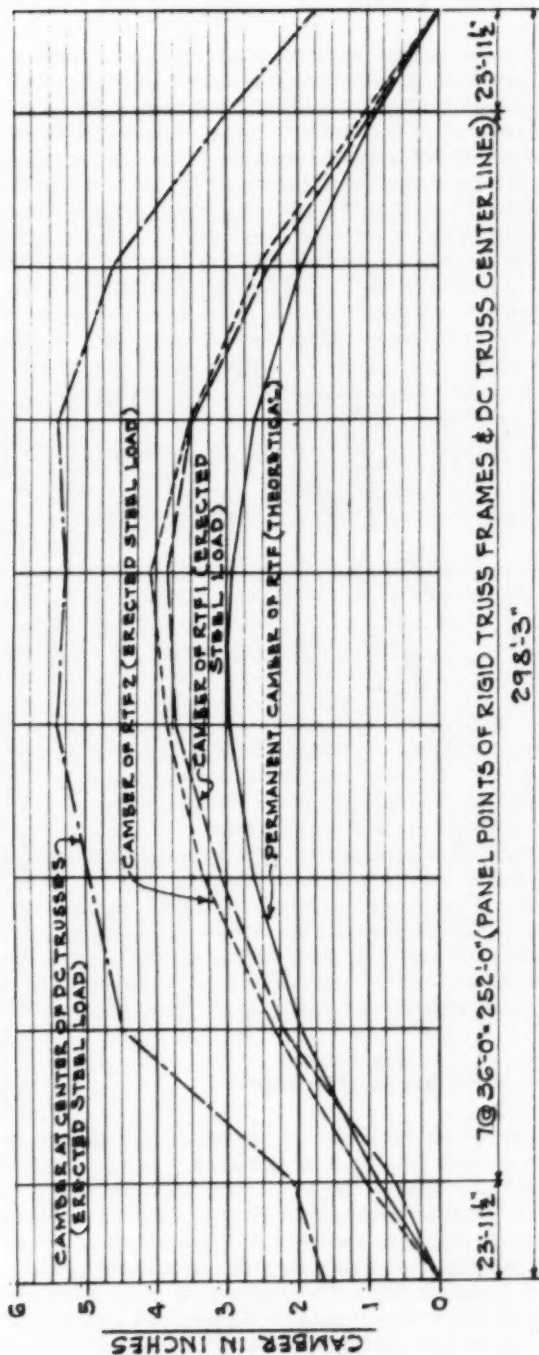
Camber and Deflection

To be able to obtain the proper camber after the dead load deflections of the large-span trusses have been taken out, provision was made in design and fabrication for all the cantilever ends of the double cantilever trusses to be erected with necessary shims, half-inch in thickness, at the bottom chord connections to the rigid truss frames. In the course of steel erection and after completion of the hangar structure, camber readings were taken of both rigid truss frames and double cantilever trusses in the early morning, noon, and in the evening. Reference temperature readings were also taken at the same time. Attempts were made to adjust the camber to a satisfactory elevation under corresponding dead load (Fig. 12). The unlocked hinges of the rigid truss frames also have been observed to determine the effect of temperature changes. The center line of the steel masonry plate was clearly established when the center line of the rigid truss frame was marked on the sole plate. These demarcations indicate relative sole plate movement with respect to the stationary base plate. Their values are plotted on the submitted graph with temperature readings as ordinates, and position of rigid truss frame sole plate as abscissae to indicate the relative movement. Steel was fabricated at the 68° F. shop temperature, and at this temperature (theoretical), the center line of the sole plate had to coincide with the center line of the steel masonry plate. From the attached curves, however, it is seen that the ratio of the translation and change in temperature, although constant, do not coincide with the theoretical curve. This discrepancy is attributed to the friction at the base and the resistance offered by tie beam supports (Fig. 13).

All in all, it could be said that the actual deflections coincided very closely with the predicted deflections.

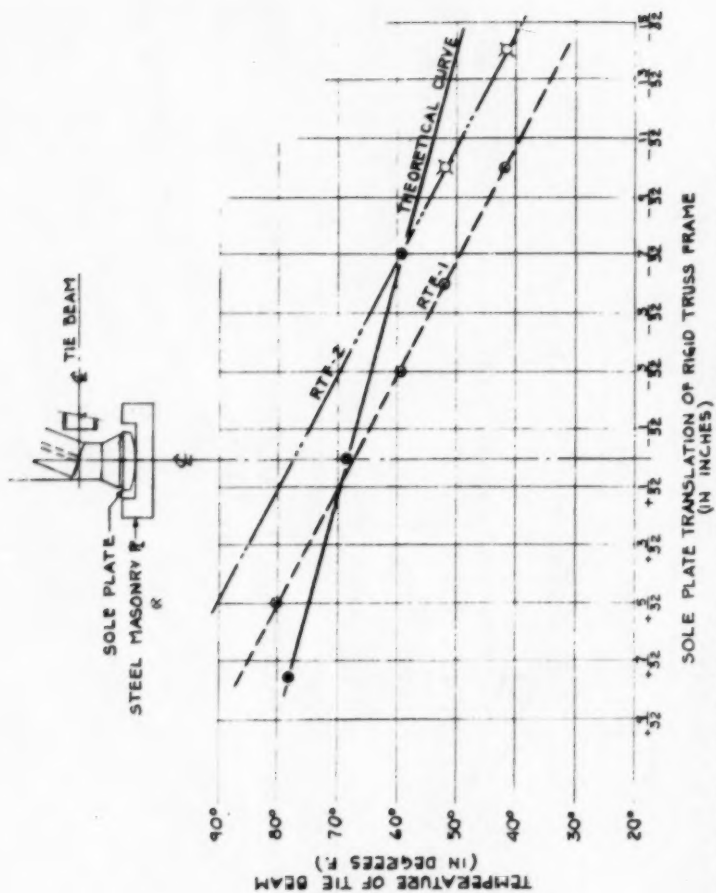






RELATIVE CAMBER OF RIGID TRUSS FRAMES

FIG.12



CURVES INDICATING RELATIVE SOLE PLATE MOVEMENTS OF RIGID TRUSS
FRAMES WITH REGARD TO TEMPERATURE VARIATIONS IN TIE BEAMS

FIG. 13

*, DENOTES EXPANSION (INCREASE IN TIE BEAM)
(-), DENOTES CONTRACTION (DECREASE IN TIE BEAM)

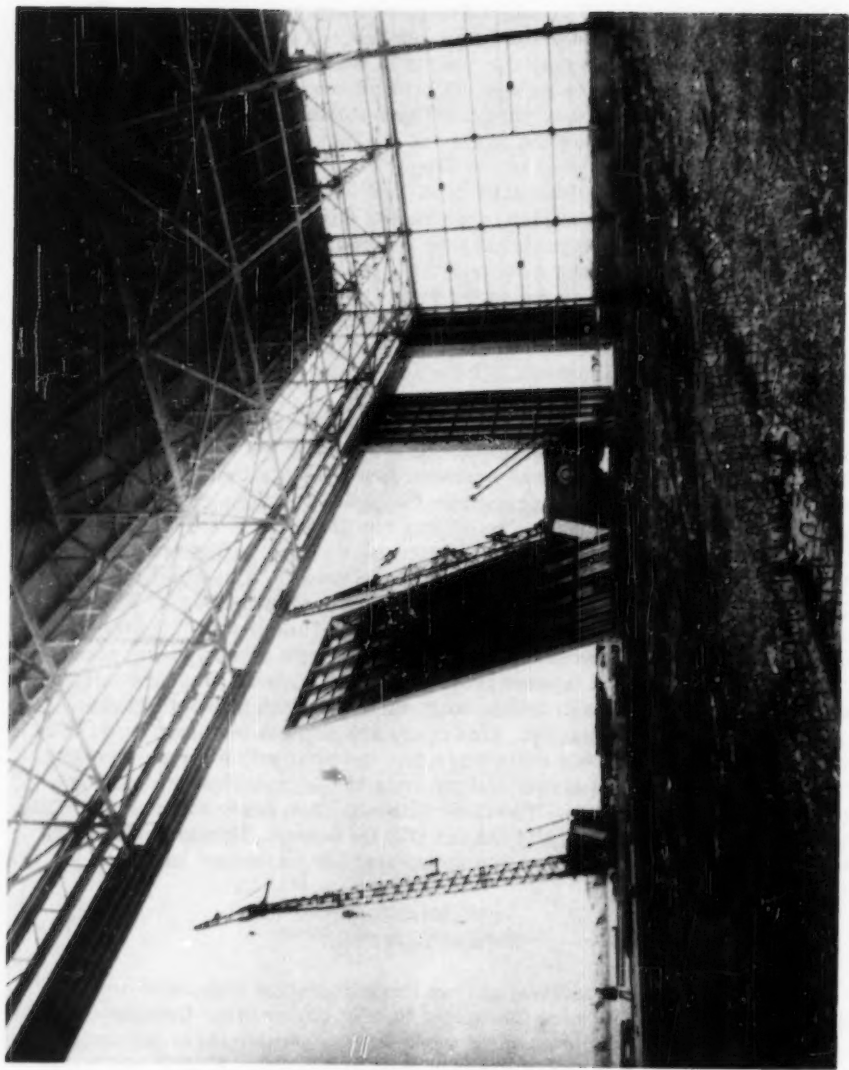
Field Allegory - Adjustment of Tie Beams

During the erection period of principal hangar steel in the summer of 1954, it was noted that considerable movement occurred in the exposed 14" WF tie beam at the end connected to the unlocked heel of the rigid truss frame. An accurate calibration of maximum movement was recorded and found to total about 1-1/2" in approximately 300-ft. tie beam length. With the advent of the winter season the beam contracted and remained in that position until March, when with the coming of warm weather, elongation occurred once again. In the interim an order from the Chief Resident Engineer prohibiting the placing of concrete floor slab unless protected by a water-tight roof had stopped the placing of the hangar floor. However, by early February sufficient area of the hangar roof had been placed to warrant the starting of the hangar floor slab (Fig. 15). At that time the weather was cool and the tie beam was still in a contracted position. To allow the contractor to proceed with the paving it was necessary to secure and permanently lock the sliding base plate connection in its calculated and centered position. This was based on the assumption that a temperature of approximately 70° F. would prevail within the enclosed trench under normal service conditions. It was, therefore, required to elongate the tie beam to an amount necessary to facilitate connection of the sole plate under this normal trench temperature.

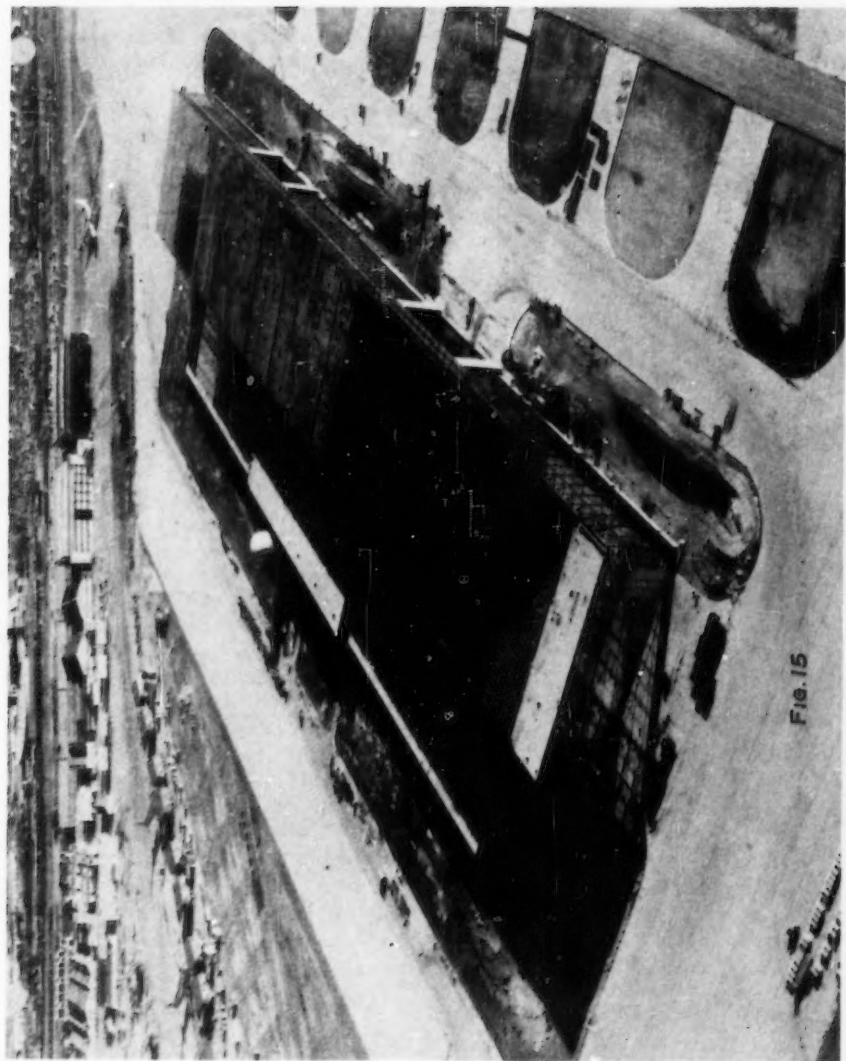
To elongate the beam presented a problem. After considerable thought, the following method was presented to the Contractor for action. First, and due to the fact that the beam was enclosed in a concrete tunnel, it was necessary to increase the temperature within the tunnel, and thereby raise the temperature of the steel beam. To do this two (2) 250,000 B.T.U. gasoline fired ground heaters were secured from the Air Force, and canvas tubes were run from the heaters into each end of the tunnel. A close check was made of the steel temperature and also of movement of the beam. The heating process required about two (2) days, at which time the sliding sole plate was about the correct position for securing. Wrought steel wedges, about 4 ft. long, 4 in. wide, and tapered from 2 in. to 0 in., were placed within the sub-base masonry plate and driven from each side with hydraulic jacks. The jacks were of 300-ton capacity. This operation brought the beam to its correct location and the anchor bolts were then secured with a torque wrench. The heat was diminished slowly and the ends of the tunnel were closed and filled with asphalt concrete. The floor slab was then ready for placing. This method was repeated on each of the ten (10) tie beams. Repeated checks on the steel have been made since, but no perceptible movement has been observed.

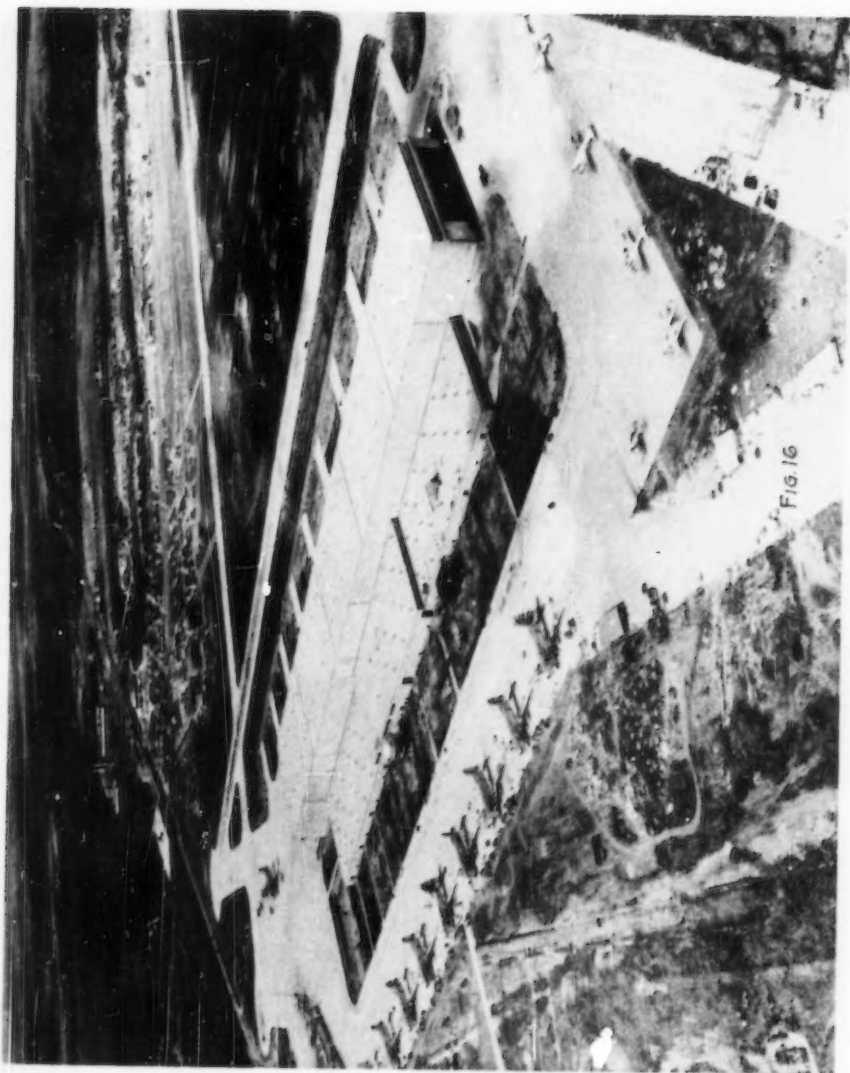
Hangar Doors

The hangar doors, consisting of four large doorways with eight metal leaves in each doorway, were fabricated by the Allison Steel Company in Arizona. The 31-ft. wide door units were subdivided into three sections to facilitate shipment from the fabricating shop to the site. A shop inspection was made for approximately 10% of the total of 96 sections for dimensional accuracy and straightness. The tolerance in length for each 11' x 61' section varied from exact length to +1/4"; width of panels were within 1/16". The 15-in. channel rails on the outside panels were within 1/4" of a straight line from top to bottom. The 12" rails, forming the underside of each door



854-26





leaf, varied out of line from 1/4" to 3/4" from top to bottom. This was not considered objectionable since each of the 12" channel rails were bolted to the side rail of the adjacent panels and the variation from the line of one side rail would tend to be corrected by the side rail bolting to it. Erection jigs were fabricated and used to lift an assembled door leaf into vertical position.

These sections were assembled and bolted into units of 31' x 61' at the hangar site and then lifted into proper position by employing American Bridge derricks equipped with 65 ft. booms. The doors were then subjected to movement under their own power and found satisfactory (Fig. 14).

Deluge Sprinkler System in Hangar

The method of placing the sprinkler mains in the hangar required considerable planning, and numerous conferences between the Mechanical Contractor and the Chief Resident Engineer's staff were held until a feasible method of operation was determined. Because of the height of the lines above the floor of the hangar, approximately 83 ft., the hazard of working with chain tongs was too great. Therefore, the following procedure was adopted.

The risers from the control valves upward were laid out on the ground and welded together, forming a single unit from the valve line to the elbow connection and the horizontal run. These risers were then lifted into place with power lines and made up. Next, the risers were hung to the steel trusses and framework. The horizontal runs of pipe sizes from 3 in. to 10 in. were made up in sections. Following this, a winch truck, with a line through a single block attached to the upper truss members, raised the sections up and placed them in the open pipe hangers. One man was located in the truss framework to guide the pipe into the hangers. The hangers were then closed and the hitch was moved to the far end of the pipe (away from the coupling end), thus exerting pressure toward the coupling. A manila line was taken from the winch truck drum and wrapped around the pipe several times. When pull was exerted on this line, it turned into the coupling, pulling it tight. On the larger lines where approved patented couplings were used, "Grunagrip," the make-up line was not provided.

Painting

In addition to the factory coat of protective paint, a field coat of conventional red lead and iron oxide paint was applied to all structural steel, including the underside of steel roof decking. Two coats of oil paint, tint green in color, were then sprayed over the structural steel members between bottom chord framing and floor slab. All sections above the bottom chord, including the underside of steel roof decking were given one spray coat of aluminum paint. The application of this aluminum paint has given an excellent brilliance to the drab structural roof framing throughout the hangar and shop proper.

SUMMARY

Progress of construction has continually kept abreast of operation schedules, and it is believed that by the end of this year the facilities will be completed and ready for occupancy and service. The modular type of design and the similitude in the principal structure has contributed greatly to the speed, ease, and efficiency with which this project has been constructed.

The contract for field inspection services was awarded to the designers of this facility with the purpose of obtaining maximum benefit of their intimate knowledge of the work involved. Provision was made in the contract for periodic inspection visits at the site by the home office engineers responsible for the design and overall execution of operations. Development and realization of this project symbolizes the new concept in air base facility design - long advocated by the Nation's top military men. It is also one in which the Air Force is exercising complete supervision of construction operations and is the sole responsibility of Air Installations Division, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio.